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SIMULATION: A SURVEY

by

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Simulation may be traced back to the beginning of time -- be it the
make-believe world of the child at play, or the adult make-believe world of
the stage. The impetus for modern scientific simulation came with the develop-
ment of analog computers in the 1930's; and progressed even further when the
electronic digital computers were created. The very definition of an analog
computer contains the notion of simulation, viz., a device which simulates
some mathematical process and in which the results of this process can be
observed as physical quantities, such as voltages, currents, or shaft positions.
While there is no doubt that the analog computer represents one aspect of
simulation, the truly new simulation advances came with the digital computer.
In the past two decades, since the development of Mark I by Howard Aiken and
since Eckert and Mauchly designed the ENIAC, tremendous strides have been made
in science and technology ascribable directly to the flourishing new computing
discipline.

The revolutionary impact of the electronic computer on our society
may well be equal to that of atomic energy -- and may actually surpass it in
the long run. A direct consequence of the computer is the burgeoning activity
which collectively goes under the name, "simulation." The growing awareness
and popularity of this field of activity is evidenced by an article in Business
Week in which a parallel is drawn between the group of simulation experts and
the group of painters known as the Futurists. Just as the art works might
bear no direct resemblance to the subjects for which they were named, so the
mathematical formulas, flow diagrams, and computer outputs bear no direct
resemblance to the physical world which they simulate. Moreover, this symbolic
art "represents a massive assault on tradition -- in this case, the traditional
art of managing large organizations."(19)   This assault -- involving scientific
systems analysis and simulation techniques -- first occurred on military systems
problems, but more recently has found its way into business and industrial
systems problems as well.

Definitions

To appraise the current work in simulation is the general purpose of this paper. In the course of my review of this area, the paper by John Harling, "Simulation Techniques in Operations Research -- A Review," (7), appeared to completely satisfy my objective. His opening remarks draw attention to the fact that "simulation" is a somewhat ill-defined subject and that considerable confusion exists in the terminology employed, and he goes on to say: "The term 'Monte Carlo' is presently somewhat fashionable; the term 'simulation' is to be preferred, because it does not suggest that the technique is limited to what is familiar to statisticians as a sampling experiment." (7, p. 307) He equates "simulation" with "Monte Carlo methods" and thereby implies a much more restrictive usage of simulation than is intended in the present survey.

The term "simulation" has recently become very popular, and probably somewhat overworked. There are many and sundry definitions of simulation, and a review and study of some of these should help in gaining a better perspective of the broad spectrum of simulation. Webster only provides the fundamental notion that simulation is an act of "assuming the appearance of, without the reality." Thomas and Deemer (24) suggest the following paraphrase of Webster: "to simulate is to attain the essence of, without the reality." Note that the substitution of "essence" for "appearance" makes the vital difference between the scientific and the casual use of simulation. It not only is not necessary that the simulator not "appear" as its real-life counterpart, but frequently attempts to imitate reality closely may be detrimental to the purposes of the simulation. For example, to expedite the training of pilots a relatively accurate duplication of the cockpit is necessary for the trainer, but to duplicate the bulky whole of the airplane would defeat the purpose of the simulator. Thomas and Deemer advise that "we should deplore the tendency to introduce trappings and ornaments in simulation to gain the 'appearance' of reality when it is the 'essence' which we need." (24, p. 5)

In a technical dictionary (9) the term "simulator" is defined as follows:

> A physical system which is analogous to a model under
> study (as, for instance, an electric network in which the
> elements are in correspondence with those of an economic
> model). The variables of interest in the model appear as
> physical variables (such as voltages and currents) and may
> be studied by an examination of the physical variables in
> the simulator. (9, p. 267)

This definition covers what is normally considered simulation when accomplished by analog or digital computers. Nonetheless, it is not the universally accepted definition, alternatives being proposed by practically each separate field of application.

Thus, in the area of Operations Research, Harling states: "By simulation is meant the technique of setting up a stochastic model of a real situation and then performing sampling experiments upon the model. The feature which distinguishes simulation from a mere sampling experiment in the classical sense is that of the stochastic model." (7, p. 307) As noted above, this definition of simulation is equivalent to the Monte Carlo technique; and is, in fact, almost identical with the definition of the latter provided by A. S. Householder:

> The Monte Carlo method may briefly be described as the
> device of studying an artificial stochastic model of a
> physical or mathematical process . . . The novelty (of the
> Monte Carlo method) lies rather in the suggestion that
> where an equation arising in a nonprobabilistic context
> demands a numerical solution not easily obtainable by stand-
> ard numerical methods, there may exist a stochastic process
> with distributions or parameters which satisfy the equation,

and it may actually be more efficient to construct such a
process and compute the statistics than to attempt to use
those standard methods (8, p. v).

While the Monte Carlo Method represents a very powerful and useful
technique in simulation, it does not encompass all the legitimate scientific
aspects of simulation.

In their book, System Engineering, Goode and Machol give a half dozen
or more examples of simulation in which the Monte Carlo Method is used in
queueing problems. They do not, however, take the foregoing definition. In-
stead, they define simulation to be "the study of a system by the cut-and-try
examination of its mathematical representation by means of a large-scale
computer." (6, p. 403) While there might be some objection to the qualifier
that a "large-scale computer" be the means of the study, modus operandi
certainly must be granted. This is an operational definition, and as such it
proposes more or less exact procedures to be followed in executing a program
of simulation. Specifically, Goode and Machol (6, pp. 404-407) propose a
series of steps including the choice of computer (analog or digital, in
particular); construction of the computational flow diagram (it being assumed
that the mathematical model of the system has been formulated); determination
of preliminary (analytical) solutions; choice of cases to be treated, with a
view toward reducing the number of runs; data reduction and analysis (some to
be done run by run); and consideration of the simulation of human beings (by
some simple analytical function or by actual inclusion in the simulation).

Another type of working definition is proposed in the field of Manage-
ment Science. Here, simulation is conceived as "the science of employing
computational models as description for the purposes of (1) learning, (2)
experimenting, (3) predicting in management problems" (23). A similar definition
which more specifically delimits the area of consideration, is the following:

> The systematic abstraction and partial duplication
> of a phenomenon for the purposes of effecting (1) the trans-
> fer of training from a synthetic environment to a real
> environment; (2) the analysis of a specific phenomenon; or
> (3) the design of a specific system in terms of certain
> conditions, behavior, and mechanisms. (1, p. 6)

The behavioral scientist, accustomed to laboratory experimentation, puts it
even more directly: "By simulation, we mean a technique of substituting a
synthetic environment for a real one -- so that it is possible to work under
laboratory conditions of control" (10).

The foregoing definitions range in emphasis from a sampling plan
(which distorts distributions in order to obtain relatively efficient estimates
of the parameters) and the mere use of a large-scale computer, to a simple
delineation of the area of inquiry. What they have in common is an attempt to
substitute other elements for some or all of the real elements of a system.
Perhaps the simplest and most direct definition of simulation is merely the
act of representing some aspects of the real world by numbers or other symbols
that can be easily manipulated in order to facilitate its study. In this
sense, simulation is one of the oldest analytical tools.

Classifications

However simulation is defined, there remains the problem of selecting
the appropriate elements of a system to be simulated. Which aspects are rep-
resented, and how they are represented, constitute the distinguishing charac-
teristics of the different types of simulation. Hopefully, these considerations
should also provide for the meaningful classification of simulation types.

After an exhaustive search of the literature, and several months'
cogitation, the writer was reluctantly forced to conclude that there is no

completely adequate taxonomy of simulation types. Perhaps some day a reasonable
basis will evolve for classifying simulation types into major and subordinate
categories, and the practitioner will be assisted thereby; but at the present
time, very little can be done in that direction.

About the best that has been proposed (see for example, I. J. Good
(5)) is a single continuum on which the model is classified according to its
degree of abstraction from the real-life system, operation, or procedure.
Thus, the focus is on the simulation model and its relationship to its real-
life counterpart. This conceptual basis for ordering simulation types
follows:

(1) At one extreme of this continuum the real system itself can be
used as the "model" to gain knowledge about itself. However direct and
simple it might sound, it is usually neither practical nor feasible to
determine the inherent properties of a system by observing its operations.
Limited time and resources often force the use of shorter, less expensive
methods than the "identity simulation."

(2) Only one step removed from the real-life instance is the attempt
to replicate it with the highest degree of fidelity, by means of an oper-
ational model of the system in its normal environment. A SAC mission
flown to test the air defenses of the United States is an example of an
essential replication of a war situation. Enemy bombers are replaced by
SAC bombers; ADC fires no weapons. Such "replication simulation" really
involves very little abstraction from reality, and also provides very
little gain; except to make possible the limited study of selected
dangerous or future situations. A subcategory of this classification
might involve essential replication of operational gear while employing
abstracted inputs. A case in point is the Air Defense Command's System
Training Program (discussed below).

(3) Next, along the continuum, the replication might be attempted in the laboratory instead of in the field. Here it is necessary to choose the relevant features of the real system for representation in the laboratory, and also to decide on the means of such representation. A system may be made up of such diverse elements as people, hardware, operating procedures, mathematical functions, and probability distributions. A laboratory model might consist of the actual replication of some elements and the abstraction and substitution by symbolic representation of others. It should be noted that every kind of substitution is possible: people are often simulated by hardware, but the reverse is also done. A wide range of simulation types is encompassed by "laboratory simulation," and perhaps is best exemplified by operational gaming.

(4) More clear-cut abstraction from reality is involved in the complete "computer simulation" of a real system. In some circles this is the only admissable type of simulation. There is no room for human beings or real hardware components in this model of the system. All aspects of the system must be reduced to logical decision rules and operations which can be programmed. If the model of the system consists only of mathematical functions, the simulation is said to be deterministic. If it also includes probability distributions then it is stochastic. This type of simulation is quite common in operations research, with a popular example being a "computer simulation" of a (hypothetical) business firm.

(5) The highest degree of abstraction leads to the complete "analytical simulation," wherein the real system is represented completely by means of a mathematical model and a solution (at least theoretically) can be obtained by analytical means. Essentially, the problem here is that of solving a set of equations. Even if a closed form is not available, approximate methods (including Monte Carlo) can be employed to get a solution. The least and the highest degrees of abstraction - "identity simulation" and complete "analytical simulation" - may not be of much experimental value, but they do provide useful conceptual bounds for the simulation continuum.

Need for further classification. -- While the foregoing considerations provide a fundamental (philosophical) continuum on which simulation types might be ordered, it is not sufficiently discriminating. The bulk of the simulation studies reported in the literature would fall into one or two categories only. Further, more detailed distinctions could lead to generalized principles and thus to the full development of a discipline of simulation. The additional dimensions of simulation cannot be adequately determined at the present rudimentary stage of development of this field.

Dichotomous classifications. -- What is frequently done as an alternative is to break the total field of simulation into two classes. Commonly encountered examples of such dichotomy, or polarity, is deterministic - stochastic; deductive - inductive; analytical - physical; computerized - manual; or one of the many variants of these. An important consideration is the absence or presence of at least one human being in the simulated model. While this seems to offer a real distinguishing characteristic, it does not help nearly as much as anticipated. There can still be stochastic models which are simulated entirely in a computer, or by means of a computer and people. For this reason, the writer discarded an earlier plan in which the primary dichotomy was into "automaton-simulation" and "bio-simulation." Differences in simulations that are fully computerized and those that involve human beings may be useful, but should probably be subordinated to more fundamental classification concepts.

Even this crude classification scheme may provide a useful guide in planning a simulation experiment. As a general rule, increasing experimental control can be attained by moving in the direction of a complete mathematical model, but unfortunately this usually is associated with decreasing realism. The more that is known about the properties of an element of a system, the better can it be simulated. Imperfectly understood system elements probably should be used "as is" in the model rather than approximated in a probabilistic

manner or by decision rules. Adequate simulation of a system in the laboratory
requires a detailed systems analysis with particular attention paid to the
functional structure of the various tasks and the operations to be performed
by the human beings in the system. Since the human actions are certainly of
a stochastic nature, realistic simulation of a man-machine system can best be
accomplished by having the human elements in the model.

Classification by objective. -- An alternative breakdown of simulation
activities can be made according to the purpose or objective of the simulation.
The principal categories usually employed are evaluation, training, and
demonstration. With the emergence of very large military command and control
systems, the old trial-and-error method had to give way to simulation as the
primary technique for the design and development of such systems, as well '
for the evaluation of alternative solutions to system problems. Again, in
the implementation and operation of such systems, simulation has been found to
be a very effective device for training. Not only have simulators been
employed for individual flight instruction in place of expensive and dangerous
procedures, but similar efficiencies have been realized in training groups in
total system operations through simulation. This is one of the chief objectives
of management games as well as the specific training programs of military
systems. In the demonstration role, simulation serves as a means of   -   .
indoctrination -- to exhibit the feasibility of a complex system.

Simulation as a Research Tool

While this very brief account of the uses of simulation for evalu-
ation, demonstration, and training immediately points up its value, some more
definite indication of the advantages of simulation as a research tool in the
study of complex systems seems to be in order. First of all, the real system
in the field is not as amenable to control as a simulation of it. At the
same time there is no interruption of the on-going activities in order to

conduct the research. Also, productive research requires the taking of
quantitative measurements, which again can better be accomplished in a simu-
lation study than by observation of the actual system.

These primary advantages are really the advantages of the laboratory
over the field, regardless of whether it is a chemistry laboratory or a digital-
computer laboratory. Simulation as a research technique has more specific
advantages:

(1) It can compress or expand real time. A business operation of
a year can be simulated in minutes in order to study long term trends or
to study the operations under varying alternatives. On the other hand,
the process can be slowed down to permit the more detailed study of
critical situations.

(2) It provides the ability to experiment, test, and evaluate new
systems or proposed changes to existing systems in advance of having to
make firm commitments. Aside from great economy of time, simulation of
this type makes it possible to consider hypothetical systems which may
be dangerous or impossible to try any other way. An interesting example
involves the procedure the Cornell Aeronautical Laboratory employed in
designing and constructing the Mark I perceptron for the automatic
identification of simple patterns. They first demonstrated by simulation
on a computer (IBM 704) that such an experimental machine could be built.

(3) It makes for more economical experimentation, both in time and
money. A complete "computer simulation" of a system usually can be run in
very short time once the program has been developed. However, the cost
of creating a large-scale computer simulation program can be prohibitive.
Usually it is justified because of continued experimentation with the
model, but on occasion the payoff may be so great as to justify even a
single trial.

(4) It permits the replication of experiments under different
conditions. An important example is the replication of economic time-
series, which just could not be accomplished without simulation.

Review of Simulation Activities

Extent of literature. -- The acceptance of simulation has been
widespread as indicated by the ever growing number of simulation studies.
Prior to 1951 there was nothing in the scientific literature on this subject.
The most recently published bibliography (18) contains 344 entries (including
6 other bibliographies) and except for one reference ("A Simplified War
Game," 1897) the earliest article is dated 1951. Two other bibliographies
merit special mention. Malcolm (14) presents what he terms "a fair sampling
of simulation literature to date." Concerned primarily with the application
of simulation to management problems, he subdivides the 165 titles into
industrial and military applications and separates simulation games from the
rest. The other (15), while not specifically addressed to simulation, presents
477 references to the closely allied subject of systems research. One of the
interesting aspects of the latter bibliography is that it also contains a
topical outline of the field and each reference is assigned to one or more of
the classification categories. The extent of the literature on simulation has
grown to such immense proportions, in so short a time, that the truly
scholarly exploration of this field looms as a formidable effort for all but
the most serious student.

No attempt is made here to review the content of different simu-
lation studies. The objective is only to indicate the scope of such studies.
One such collection of 17 studies appears in the report of "System Simulation
Symposium" (22). These include typical inventory-control, scheduling, cargo
handling, and waiting-line problems on the industrial side; related problems
on logistics systems peculiar to the military, as well as military "laboratory
simulation," incorporating systems of men and equipment; and even some
methodological considerations directed at increasing the speed of simulation
and statistical problems associated with Monte Carlo sampling.

As regards the technical aspects of simulation, the results of current research activities appear, principally, in the Operations Research journal, specialized statistical journals, and publications of various research institutes and symposia. Of special interest is the report of the first Symposium on the Monte Carlo Method (8) and two subsequent symposia (20, 21) on the same subject.

Operational gaming. -- The simulation studies that have attracted the most attention in recent years may be described by the generic term "games" - intended to cover such activities as war gaming, business management games, and operational gaming in general. In their excellent article, Thomas and Deemer (24) first distinguish the basic concepts of simulation, Monte Carlo, and operational gaming; present a brief review of some of the theory of games of strategy; and then compare the approaches of gaming and non-gaming techniques to competitive situations. The role of operational gaming is best expressed in their words:

> Although simulation and Monte Carlo methods
> are often used in gaming we feel that the essence
> of operational gaming lies rather in its emphasis
> on the playing of a game. There is playing to
> formulate a game, playing to solve a game, and
> playing to impart present knowledge of a game.
> Thus we define operational gaming as the serious
> use of playing as a primary device to formulate
> a game, to solve a game, or to impart something of
> the solution of a game. (24, p.6)

In practical applications, the technique of gaming is aimed principally at providing practice in working through alternative sequences in considerable detail. Within the framework of a particular game certain input parameters can be altered to provide innumerable variations. When human teams

participate in such games, they not only gain practice in comprehending the
consequences of particular moves and sequences of events, but also gain some
insight into the perspective of the participants.

The development and present usage of management games is reviewed
by Joel Kibbee (11). He stresses the importance of computers in this area,
and discusses the building of models and programming of management games. It
should be remembered that non-computer or manual business games (e.g., as
developed by Stanley Vance at the University of Oregon, and by John L.
Kennedy at Princeton University) have considerable merit as tools for manage-
ment training and development as well.

Management control. -- Perhaps one of the most powerful tools for
management control of large-scale programs is the activity known as PERT
(Program Evaluation Review Technique). This system of charting the key milestones
into a network for the accomplishment of an objective, dependent on many and
diverse factors, was first developed in conjunction with the Polaris program
(13). As a result of such management control, the Polaris program became
operational two years earlier than originally anticipated. A similar technique
developed for the Air Force by Douglas Aircraft Company in conjunction with
the Skybolt program is PEP (Program Evaluation Procedure). Independently,
Wright Air Development Division programmed a Univac 1103A for PEP analyses.
The PERT/PEP program evaluation techniques now are being extended to almost
all Army, Navy, and Air Force weapons systems (12). Among other computer-
based methods for monitoring schedules is SCANS (Scheduling and Control by
Automated Network Systems), developed at System Development Corporation. The
aspect of these techniques which is especially germane to the theme of this
paper is the optimization of networks through simulation. By devising a
"computer simulation" of the scheduling technique, alternative management
decisions can be tried, and from the output an optimal solution can be
determined. Closely related to these types of programs is the Decision Gaming
work reported by Dr. Vazonyi (25).

Social Behavior. - - Turning to another area, Ellis Scott (17),
calls attention to dozens of studies on simulation of social processes being
carried out in universities and research laboratories from coast to coast.
His survey is concerned with research in the behavioral sciences which use
computers in the simulation of social behavior. The studies range from
experiments in interactions and conformity of small groups, to intergroup
relations in the community, to the behavior of an entire society and inter-
national relations.

Vehicular traffic. - - Still another area which is receiving more
and more attention is that of vehicular traffic control. While the earliest
works, by H. H. Goode, G. F. Newell, and others, only date back about six
years, the activity has been gaining considerable momentum since then.
Research is going on in all parts of the country. The extent of the national
interest is evidenced by the conference on transportation research convened
by the National Academy of Sciences in late 1960. About 150 participants from
government, industry, universities, and research institutions met to review
and formulate a program of research on transportation in the United States.
A later conference (16) was devoted exclusively to the utilization of
simulation as a research tool in the areas of highway and vehicle improve-
ment, traffic control and enforcement, and driver and safety education.

An example of a physical model for studying driver performance,
car construction, and road design is the "driving simulator" at the UCLA
Institute of Transportation and Traffic Engineering. The cab of this simu-
lator consists of a standard station wagon on a treadmill of steel rollers,
which faces a 10-ft high semicircular screen and with a small screen on the
car's rear window. Movie projectors throw traffic scenes on both screens and
a battery of instruments record changes in steeringwheel movement, acceleration,
braking, and in the driver's breathing rate and in emotional stress.

Although the ultimate goal is to consider the total system, including the driver and the traffic, at this stage of development of methodology, it seems wise to distinguish "driving simulation" from "traffic simulation." Early work on traffic simulation was restricted to one or two lanes of very short stretches of highway, and required inordinate amounts of computer time. Nonetheless, such work pointed to the feasibility of running simulation studies of traffic flow. A much more extensive model of expressway traffic flow has been developed at the Midwest Research Institute, and is reported by Glickstein and Levy (4).

Simulation in Man-Machine Laboratory Research

The foregoing review points to many exciting and challenging activities - emerging as a result of the development of the digital electronic computer, the use of simulation, and the increased awareness of the "systems approach." Thus, the study of large, complex man-machine systems has become possible.

Just as trial-and-error experimentation has been a respected technique in the development of the classical sciences, so in the study of complex systems the new techniques of simulation may be employed to explore and to define the problem itself. The direction and course of study of a man-machine system should be permitted (at least in the early stages) to be altered and restructured during the simulation and according to insights gained from the simulation itself. This use of simulation as a new kind of research tool is perhaps the outstanding feature of such laboratories as RAND's Logistics Systems Laboratory and SDC's Systems Simulation Research Laboratory, discussed below.

NEWS. -- Entire laboratories have been built to exploit simulation for teaching purposes and evaluation of systems. Perhaps the first such facility to be conceived (in 1945), but which was not funded until 1950 and

then took eight years to build, is the simulator at the U.S. Naval War College
at Newport, Rhode Island. This facility and the exercise conducted in it is
called NEWS (Naval Electronic Warfare Simulator). At the heart of the system
is a very large analog computer (known as the Damage Computer) which is
designed primarily to assess damage and to provide feedback to the several
forces playing, to indicate their remaining effectiveness. The exercise is
primarily a training device - used in war gaming, in the final stages of
tactical training of naval officers from the fleet.

SRL. - - Another laboratory in which simulation was employed as the
principal tool was the Systems Research Laboratory (SRL) of The RAND Corporation.
From 1951 to 1954 this laboratory employed simulation to generate stimuli for
the study of information processing centers. The essential features of a radar
site were created in the laboratory and by carefully controlling the synthetic
inputs to the system and recording the behavior of the group it was possible
to study the effectiveness of various man-machine combinations and procedures.

STP. -- The research in SRL eventually gave rise to the Air Defense
Command's System Training Program (STP) - probably the largest-scale simu-
lation effort ever attempted. STP is now in operation throughout the United
States, as well as in Alaska, Canada, and Europe. Training exercises are
conducted in the normal working environment at the radar sites, direction
centers in the SAGE system, Division Headquarters, and higher commands.
Fundamental to this vast program is the creation of problem materials by
means of an IBM 7090 and special off-line and EAM equipment. Through these
means synchronized radar pictures for large areas of the country are simulated
along with other inputs required by the operating system, e.g., flight plan
information, intelligence and weather information, and commands from higher
headquarters. Also, various lists and maps are prepared for the trainers to
assist them in observing and recording crew actions in order to furnish
feedback on system performance to the crew immediately after each exercise.
Through simulation of this type it is possible to provide exercise of air

defense procedures and regulations, applicable either in peace or in war situations, at a fraction of what it would cost with "replication simulation."

LSL. -- In 1956, the Logistics Systems Laboratory (LSL) was established at RAND under Air Force sponsorship. The first study in this laboratory involved the simulation of two large logistics systems for purposes of comparing their effectiveness under different governing policies and resources. The system consisted of men and machine resources together with policy rules on the use of such resources in simulated stress situations such as war. The simulated environment required a certain amount of aircraft in flying and alert states while the systems' capability to meet these objectives were limited by malfunctioning parts, procurement and transportation delays, etc. The human participants represented management personnel while higher echelon policies in the utilization of resources were simulated in the computer. The ultimate criteria of the effectiveness of the systems were the number of aircraft in commission and dollar costs. While the purpose of the first study in LSL was to test the feasibility of introducing new procedures into an existing Air Force logistics system and to compare the modified system with the original one, the second laboratory problem has quite a different objective. Its purpose is to improve the design of the operational control system through the use of simulation. A complete description of this study is presented by Geisler and Steger (3).

ASDEC. -- A somewhat different type of facility in which simulation is employed to test and evaluate electronic systems is the Applied Systems Development Evaluation Center (ASDEC) of the Naval Electronics Laboratory at San Diego. Recently the Navy Tactical Data System was being evaluated. The operational system was simulated by means of actual hardware components such as the Univac M460 computer and cardboard mockups of display and control equipment. The facility includes an analog-to-digital computer which generates synthetic radar data used in the testing of operational systems.

NBS Study. -- Perhaps the largest single step leading to the exploitation of simulation for research purposes was the Feasibility Study (2) conducted by the National Bureau of Standards. The broad objectives of this study are best indicated in its opening paragraph:

> This report presents the results of a study of the feasibility, design, and cost of a large-scale tool to be used in a research program on man-machine systems. This tool facilitates the simulation of complex weapons systems for purposes of laboratory experimentation with human subjects in the system feedback loops. It is intended to aid in the optimization of system performance through studies of man-machine dynamics. It incorporates capabilities which represent a substantial advance over those of existing facilities for research on man-machine systems.

Feasibility was demonstrated through the actual design, implementation and operation of a scale model of the desired facility. The work done at the National Bureau of Standards provided the fundamental guidelines and philosophy for the more ambitious laboratory facility built by the System Development Corporation in Santa Monica.

SSRL.-- Recognizing the importance of recent work in simulation, as well as recognizing the need for continued and expanded support for the further development of this area, with particular emphasis on its use in the study of complex man-machine systems, SDC decided to create a general-purpose, computer-based, facility in which such research could be conducted. Plans for the Systems Simulation Research Laboratory (SSRL) were initiated in late 1959, and the Laboratory became operational in 1961.

The physical facility includes about 20,000 square feet. The main experimental operations space is a room approximately 45 x 50 feet with 20-foot clearance from floor to ceiling. It is completely surrounded by an elevated observation area. This large room may be divided into appropriate smaller areas by means of movable walls. Adjacent to the large, high-ceiling space are smaller, standard height experimental areas, which also may be adjusted in size and shape to accommodate the operations and observation requirements of specific projects.

A basic concept in planning a laboratory of this kind is the distinction between universal-type and project-specific type equipment. Of the former type, the most important is the general-purpose digital computer, a Philco 2000 system. Another major piece of equipment is a transducer that permits human beings and other real-time elements of a system to communicate with the computer. Such a real-time switch and storage unit (RL-101), designed and built at SDC, is completely integrated with the computer. An internal telephone system (up to 120 stations), a public address system, recording facilities for any audio line, more than 20 teletypewriters, CRT situation and tabular displays, and a closed-circuit television system round out the general-purpose equipment of the laboratory. The specific hardware requirements for the first couple of projects include special desks and student-input devices, and controller facades.

Another basic concept is a general-purpose programming system. Perhaps some day there will truly be a general-purpose simulation program which will greatly facilitate the execution of research projects. For the present, however, the only generality is the basic utility program system for the Philco 2000 operating with the RL-101 and certain standard subroutines. A special problem oriented language, known as JOVIAL and patterned after Algol (the International Algebraic Language) is used at SDC. The principal effort involved the preparation of a JOVIAL Translator for the Philco 2000. Also,

an executive control program has been developed which takes cognizance of the
requirements introduced by the RL-101 and of the unusual nature of the
applications of the Philco 2000.

The new laboratory is expected to enhance the present research
efforts of SDC and to open entirely new avenues of research endeavor. In the
former category are a number of research projects that have necessarily been
limited in scope, but which can now be broadened because of the new facilities.
One such area is that of automated teaching. Successful research in this area
has been conducted at SDC for several years, but the constraint of a single
student to the teaching machine has been a severe limitation. This made the
gathering of statistical data very time consuming. Also, any potential appli-
cation of automated teaching techniques in the academic or the military or
industrial organizations would certainly require more efficient means than
individual tutoring. Thus, the next stage in this research effort involved
the creation of a Computerized Laboratory School System (CLASS), made possible
in SSRL.

Another example of present research at SDC which can be expanded
through the medium of the new laboratory is the study of Management Control
Systems. Research accomplishments to date consists of a "computer simulation"
of the behavior of a business system. This model enables the study of the
reaction of the organization to specific changes under alternative sets of
decision rules. As interesting as the computer simulation might be, it will
be found lacking in a basic ingredient insofar as acceptance by real-world
managers is concerned. That ingredient is the true human variability in
decision making. The particular model certainly can be made more valid -
albeit, more complex and less controllable - by introducing human decision
makers at certain critical points in place of decision rules. Such a
"laboratory simulation" model, at a later phase of the research, is con-
templated in SSRL.

The first new research endeavor to exploit the SSRL facilities is a
study of a terminal air traffic control system operating in a post-1970 air
environment. Projected increases in traffic volume and aircraft speeds indicate
that terminal control zones will increase in size and will therefore include
many airports within a single complex. Coordination among many airports of the
control of high density traffic of widely differing performance characteristics
poses significant problems of organization and planning. It is believed that
in order to effect the safe, orderly and expeditious flow of air traffic in
a terminal complex, there will be a need for a new planning agency in addition
to the control agencies in intimate contact with the details of the environment.
The general purpose of this project is to investigate the functional inter-
actions among the control agencies, and to evolve alternative hypotheses re-
garding superordinate planning agencies.

In the first phase of the project the configuration simulated is an
air traffic control system for a two-airport terminal complex. The system
consists of representations of various agencies for each of the two airports.
Some of these agencies include human operators while others are represented
completely by automatic processes. The objectives of Phase I are to study
inter-airport coordination problems and to identify significant variables for
future systematic investigation. Additional planning and coordination
functions will be added in subsequent configurations as they are indicated by
Phase I results. This project - involving a "laboratory simulation" model -
is an excellent example of the utilization of the best aspects of the broad
range of simulation techniques in order to experiment with a complex man-
machine system.

In the wide range of simulation work reviewed in this paper two
distinct activities stand out, neither one taking much cognizance of the
other. On the one hand, simulation work is being done in the Operations
Research field which may be classified largely as "computer simulation." On

the other hand, there is the group of behavioral scientists, experimental psychologists in particular, engaged in the simulation of environmental conditions which may be called "laboratory simulation." Each of these groups could learn a great deal from the other. Furthermore, there is increasing evidence that "pure" simulation will have to be modified if it is to stand the test of validation. What is necessary is the marriage of the two approaches - a realistic possibility in the new man-machine system laboratory.

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Unclassified report

DESCRIPTORS: Simulation. Monte Carlo
Method.

Appraises the current work in simulation.
Reviews definitions of the word "simulation".
Reports that while the Monte Carlo Method
represents a very powerful and useful

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technique in simulation, it does
not encompass all the legitimate
scientific aspects of simulation.
States that the selection of appropriate
elements of a system to be simulated
and the classification of simulation
types remain continuous problems in the
field of simulation. Discusses the
advantages of simulation as a research
tool, and reviews simulation activities.
Describes the Systems Simulation Research
Laboratory (SSRL) which became operational
at System Development Corporation in 1961.